

# The BeppoSAX view of NLS1s

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The main results of broad band (0.1–10 keV) BeppoSAX observations of a selected sample of NLS1s are presented and discussed. It is shown that all the available data are consistent with a scenario in which NLS1s are running at a high accretion rate.

*Key words:* X-rays: galaxies – galaxies: Seyfert – galaxies: individual: Ton S 180, Ark 564, PKS 0558–504, PG 1115+407, RE J1034+396, IRAS 13224–3809, IRAS 13349+2438

## 1 Introduction

An observational program of a small sample of Narrow Line Seyfert 1 Galaxies (NLS1s) has been carried out with BeppoSAX with the aim to investigate the broad band X-ray spectral and variability properties of these objects. The capabilities of the BeppoSAX detectors, and especially the relatively large MECS effective area at high energy ( $> 5$  keV), have been fully exploited to further investigate, with respect to previous ROSAT and ASCA observations, several of the distinctive properties of NLS1s. More specifically, we want to test whether the 2–10 keV spectral index distribution and the properties of the iron K-shell features in the 6–10 keV region are different from those of normal, broad-line Seyfert 1s (BLS1s). In addition, the broad energy range covered by the BeppoSAX LECS (0.1–4 keV), MECS (2–10 keV), and PDS (13–100 keV) detectors will be used to constrain the overall shape of the X-ray continuum and in particular the strength of the soft excess component and the nature of the 1 keV absorption/emission features reported in several ASCA observations (13), (9), (22), (15), (23), (25), (26). In this paper, a summary of the most important results obtained by BeppoSAX are presented and discussed. A more detailed analysis of the X-ray observations complemented by optical and UV data for some sources can be found elsewhere : (6), (7), (20).

Table 1  
The BeppoSAX sample

Source	Date	Exposures (sec)		Count Rate (cts/sec)	
		LECS	MECS	LECS <sup>a</sup>	MECS <sup>b</sup>
Ark 564	14/11/97	12574	26196	0.254±0.005	0.170±0.003
Ark 564	12/06/98	20209	46765	0.250±0.004	0.169±0.002
Ark 564	22/11/98	11963	29154	0.255±0.005	0.186±0.003
PKS 0558–504	18/10/98	33169	64021	0.126±0.002	0.165±0.002
Ton S 180	03/12/96	12014	24913	0.092±0.003	0.068±0.002
IRAS 13349+2438	13/01/00	25327	69552	0.056±0.002	0.053±0.001
RE J1034+396	18/04/97	21347	43183	0.066±0.002	0.016±0.001
PG 1115+407	02/05/97	17078	33798	0.016±0.001	0.012±0.001
IRAS 13224–3809	29/01/98	17304	39279	0.009±0.001	0.006±0.0006

<sup>a</sup> in the 0.2–2 keV energy range; <sup>b</sup> in the 2–10 keV energy range

## 2 The sample

The BeppoSAX NLS1 Core Program includes some of the brightest and most variable objects previously observed by ROSAT and/or ASCA (Table 1). We have also considered the optically selected quasar PG 1115+407, observed in a different BeppoSAX program, since its optical and X-ray properties satisfy the NLS1 definition.

All datasets were analyzed in a uniform way using the standard data reduction techniques described in (8). All objects have been clearly detected by the imaging LECS and MECS detectors, while only two positive detections (PKS 0558–504 and PG 1115+407) are found in the PDS instrument. Unfortunately, in both cases the spectrum above 10 keV is poorly constrained. For PKS 0558–504, the PDS data are consistent with the extrapolation of the 2–10 keV spectrum. A spectral flattening seems to be present in PG 1115+407 which may be due to contaminating sources in the field of view (17).

## 3 The 2–10 keV spectrum

The MECS datasets of the entire sample were fitted with a single power law model plus Galactic absorption. This model provides an acceptable description

Table 2  
MECS spectral fits in the 2–10 keV energy range

Source	$z$	$\alpha$	$\chi^2/\text{d.o.f.}$	$F_{2-10\text{keV}}^a$	$L_{2-10\text{keV}}^b$
Ark 564 <sup>c</sup>	0.025	1.41±0.03	95.2/68	14.7	0.4
PKS 0558–504	0.137	0.97±0.04	134.5/141	15.4	14
Ton S 180	0.062	1.28±0.12	69.1/64	3.9	0.7
IRAS 13349+2438	0.108	0.89±0.09	104.6/96	3.6	2.0
RE J1034+396	0.042	1.42±0.26	31.5/45	0.86	0.07
PG 1115+407	0.154	1.35±0.27	23.0/26	0.85	1.1
IRAS 13224–3809	0.067	0.62±0.45	16.6/17	0.49	0.1

<sup>a</sup> units of  $10^{-12}$  erg cm<sup>-2</sup> s<sup>-1</sup>

<sup>b</sup> units of  $10^{44}$  erg s<sup>-1</sup> ;  $H_0 = 50$  km s<sup>-1</sup> Mpc<sup>-1</sup> ,  $q_0=0$

<sup>c</sup> 3 observations merged

of the X-ray continuum and the results of individual fits are reported in Table 2. The average slope is  $\alpha = 1.13$  with a large associated dispersion of  $\sigma = 0.31$ . Excluding the faintest source in the sample (IRAS 13224–3809), for which the slope is poorly constrained, we find  $\langle \alpha \rangle = 1.22 \pm 0.23$ , fully consistent with the weighted average value of 1.23 for the whole sample. The small number of objects does not allow a detailed comparison with the 2–10 keV slopes of BLS1s and quasars, even though it is clear that the 2–10 keV energy index distribution of NLS1s is shifted toward higher values compared to that of BLS1s, in agreement with previous findings (4), (15), (26). A steep 2–10 keV spectrum is expected by two-phase thermal Comptonization models (11) if a significant fraction of the accretion power is dissipated in the disc phase. This hypothesis is supported by the presence of strong soft components in most of the objects (see § 6).

#### 4 Hard X-ray variability

Substantial flux variability (up to a factor of 2) in both the soft and hard X-ray bands is detected in all sources except REJ 1034+396 on timescales of the order of a few thousands of seconds, confirming the temporal behaviour established by ROSAT (2) and ASCA (14), (24) observations. The analysis of hardness-ratio light curves indicates the lack of significant spectral variability (6), (7). After the discovery of extremely rapid (doubling time of about 800 s) soft X-ray variability in the ROSAT observation of IRAS 13224–3809 (1), several intensive monitoring programs of a few NLS1s have been successfully

carried out with the ROSAT HRI, allowing a better sampling of the light curves. Several episodes of rapid soft X-ray variability with extremely high amplitude (up to a factor of 50–60) have been detected in IRAS 13224–3809 (3), PHL 1092 (5) and PKS 0558–504 (10). Relativistic effects and/or obscuration by thick matter with a small covering factor have been proposed (see Brandt, this volume).

The BeppoSAX 2–10 keV light curve of the rapidly variable NLS1 IRAS 13224–3809 (Fig. 1) indicates that relatively rapid high amplitude variability is also present at high energies. Unfortunately the faint X-ray state and the short exposure time do not allow a more detailed analysis and a comparison between soft and hard X-ray light curves.

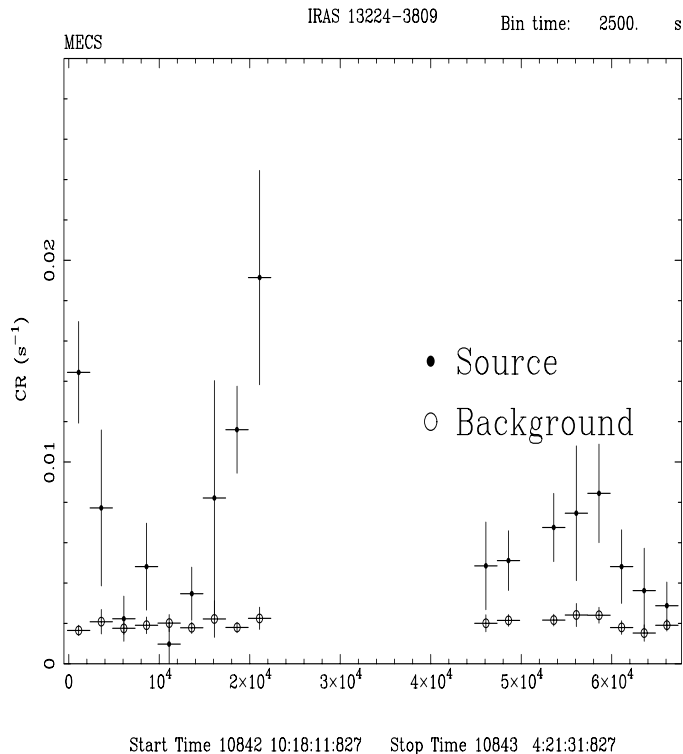


Fig. 1. The hard X-ray light curve of IRAS 13224–3809.

## 5 Iron Features

The search for iron  $K\alpha$  emission lines gave positive results, although at different levels of significance, in 3 objects: Ton S 180 (6), Ark 564 (7) and PG 1115+407 (17). The best fit energy centroid, significantly higher than 6.4 keV (between 6.7 and 7 keV), and the observed equivalent widths of the order of 500 eV in Ton S 180 and PG 1115+407, strongly suggest emission from highly ionized gas. There is no evidence of line-like features in the other objects but it should be noted that the signal to noise at high energies is rather

poor. The lack of line emission in the good quality spectrum of the radio-loud quasar PKS 0558–504 can be explained assuming a substantial contribution from the non-thermal component.

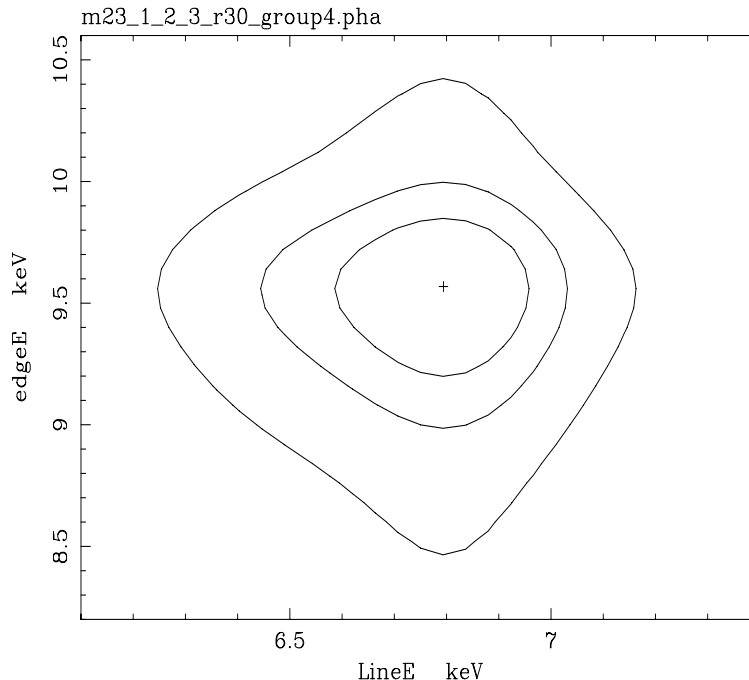


Fig. 2. The 68, 90 and 99% confidence contours of the iron line and edge energies in the BeppoSAX spectrum of Ark 564.

The residuals of a single power law fit to the high energy spectrum of Ark 564 suggest the presence of an edge-like feature at  $E > 8$  keV in addition to the ionized iron line (Fig. 2). The best fit energy and optical depth of the absorption edge are consistent with those recently reported from the analysis of simultaneous ASCA and RXTE observations (25).

The presence of emission lines and absorption edges originating in a highly ionized environment seems to be a distinctive property of the BeppoSAX NLS1 sample. In this respect it is worth noting the tentative detection ( $2\sigma$ ) of a line-like excess at about 6.7 keV in the ASCA spectrum of RE J1034+396 (19). A straightforward interpretation of the line properties is obtained if they are produced in the surface layers of a strongly ionized accretion disc (16).

## 6 Broad band spectra

The LECS plus MECS data of all sources have been fitted with various models leaving the relative normalizations free to vary in order to take into account residual intercalibration systematic uncertainties (8). A single component model never provides an acceptable fit to the 0.1–10 keV continuum. The

residuals of a single power law fit to the IRAS 13349+2438 spectrum (Fig. 3) are representative of the typical behaviour observed in the BeppoSAX NLS1 sample and clearly illustrate the need for at least two components.

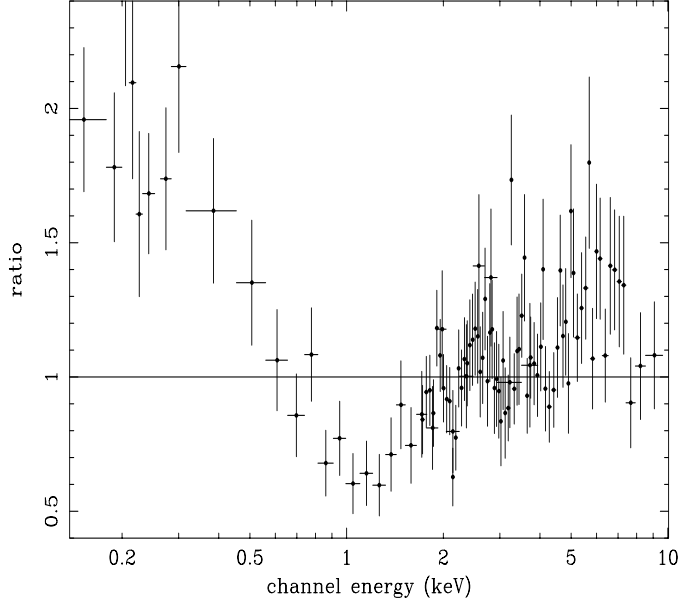


Fig. 3. The residuals of a single power law fit to the 0.1–10 keV spectrum of IRAS 13349+2438.

The best fit spectral parameters, assuming Galactic absorption and neglecting the high energy emission/absorption features, are summarized in Table 3 together with the corresponding unabsorbed luminosities in the 0.1–2 and 2–10 keV bands. Even though the soft X-ray flux is always larger than that in the hard X-rays, there is a relatively wide range in the shape and intensity of the soft excess component. The high energy tail of blackbody emission provides a good description of the soft X-ray spectrum for 5 (out of 7) objects. Not surprisingly, the strongest soft excesses (last column of table 3) correspond to the highest temperatures and an additional blackbody component is required to fit the lowest energy (below 0.3–0.4 keV) part of the spectrum in RE J1034+396 and Ark 564. The double blackbody mimics a multitemperature optically thick disc model. If this is the case, the fitted range of temperatures would imply small black hole masses. A broken power law model is preferred for the radio-loud quasar PKS 0558–504 and for Ton S 180. In the former case the X-ray emission mechanism is probably different and likely to be related to the radio properties. In the latter, the overall energy distribution peaks in the far ultraviolet (6) suggesting a lower accretion disc temperature and thus a negligible contribution in the X-ray band.

Several features resembling absorption edges were found in the 1–2 keV ASCA spectra of 3 NLS1s including IRAS 13224–3809 (13), while line-like excess

Table 3  
LECS+MECS spectral fits in the 0.1–10 keV energy range

Double Blackbody plus power law						
Source	$N_{Hgal}^a$	$kT_s^b$	$kT_h^b$	$\alpha_h$	$L_{soft}^c$	SXD <sup>d</sup>
RE J1034+396	1.5	55±10	155±25	1.19±0.24	1.6	23
Ark 564	6.4	35 <sup>+17</sup> <sub>-11</sub>	154±7	1.41±0.04	4	10
Blackbody plus Power Law						
Source	$N_{Hgal}$	$kT^b$	$\alpha_s/E_{break}$	$\alpha_h$	$L_{soft}^c$	SXD <sup>d</sup>
IRAS 13224–3809	4.8	117±17	...	0.64±0.35	0.9	9
PG 1115+407 <sup>e</sup>	1.7	57 <sup>+31</sup> <sub>-40</sub>	2.6/0.4	1.28±0.13	5	5
IRAS 13349+2438 <sup>e</sup>	1.1	81 <sup>+7</sup> <sub>-10</sub>	1.8/1.0	0.82±0.06	5	2.5
Broken Power Law						
Source	$N_{Hgal}$	$\alpha_s$	$E_{break}$	$\alpha_h$	$L_{soft}^c$	SXD <sup>d</sup>
Ton S 180	1.5	1.68±0.07	2.5 <sup>+0.5</sup> <sub>-0.9</sub>	1.29 <sup>+0.12</sup> <sub>-0.19</sub>	4.9	7
PKS 0558–504	4.9	1.29 <sup>+0.16</sup> <sub>-0.09</sub>	1.1 <sup>+0.3</sup> <sub>-0.6</sub>	1.04±0.03	29	2

<sup>a</sup> Galactic column density (units of  $10^{20} \text{ cm}^{-2}$ )

<sup>b</sup> Blackbody temperature (in eV)

<sup>c</sup> Unabsorbed 0.1–2 keV luminosity (units of  $10^{44} \text{ erg s}^{-1}$ )

<sup>d</sup> Soft X-ray dominance (defined as  $L_{0.1-2 \text{ keV}}/L_{2-10 \text{ keV}}$ )

<sup>e</sup> The BB plus PL model is only slightly better than the Broken PL fits ( $\Delta\chi^2 \sim 2$ )

emission was discovered around 1 keV in a few other objects observed with ASCA (9), (15), (26) including Ton S 180 (22) and Ark 564 (25), (23). The nature of these features is still not well understood. If the absorption edges are due to oxygen (the primary source of opacity in photoionized gas), the observed energies would imply relativistic outflows (see (13) for more details). Alternatively, a blend of resonance absorption lines in a highly ionized gas (18) could provide a viable explanation. For some values of the ionization parameter, the accretion disc reflection spectrum is rich in emission lines (21). Indeed, it has been proposed that the 1 keV emission features in Ton S 180 and Ark 564 are due to a blend of such lines (22) and/or to O VIII recombination continuum emission (25).

There is no convincing evidence of emission lines and/or absorption edges in any of the 0.1–2 keV BeppoSAX spectra when the best fit models of table 3 are adopted (e.g. Fig. 4). The origin of the discrepancy with the ASCA results is likely to be due both to the different energy resolution and spectral coverage of the detectors onboard ASCA and BeppoSAX.

In order to check whether the relatively weak emission line detected by ASCA

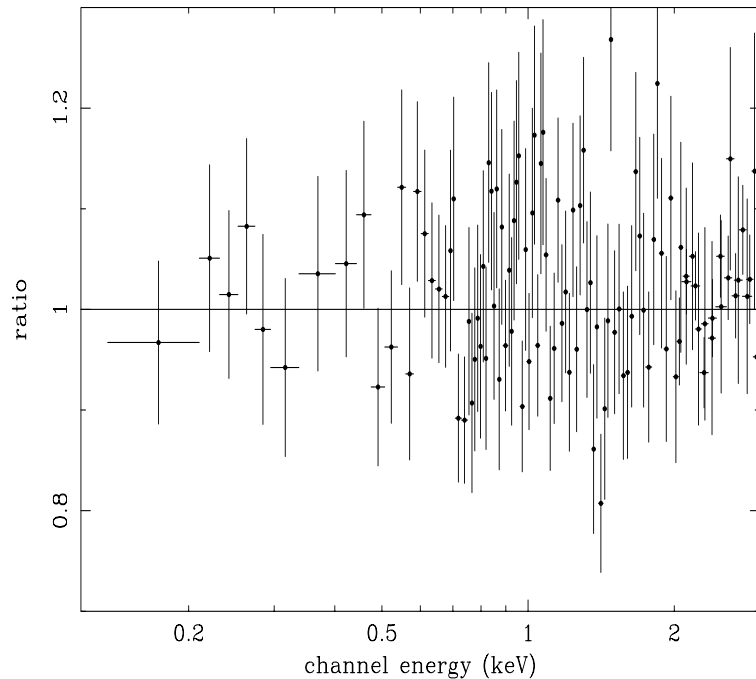


Fig. 4. The residuals of the best fit model (Table 3) to the 0.1–3 keV spectrum of Ark 564.

could have been missed by the BeppoSAX LECS, a simulated 100 ksec BeppoSAX observation of Ark 564 was produced with the best fit ASCA parameters quoted by (23). Given that the simulated spectrum is well described by the best fit model of Table 3, it turns out that weak soft X-ray emission features can hardly be studied with BeppoSAX. On the other hand, the lack of sensitivity of the ASCA instruments below  $\sim 0.6$  keV coupled with the calibration uncertainties at these energies, prevent a detailed modeling of the soft X-ray continuum and of the strength of any emission/absorption features. An emission line at  $\sim 1$  keV is still statistically required if the ASCA spectrum is fitted with a blackbody plus power law model; however the derived line EW is about a factor of 2 lower than that obtained without a blackbody component.

## 7 Conclusions

The present results fit fairly well with the hypothesis of a higher accretion rate relative to the Eddington rate in NLS1s with respect to BLS1s. If the energy conversion efficiency is the same, NLS1s should have smaller black hole masses and a correspondingly higher accretion disc temperature. The steep soft excess and the good fit obtained with thermal components are explained by a shift of the accretion disc spectrum in the soft X-ray band, while the rapid variability is naturally accounted for by the small black hole mass. The strong soft excess could lead to a strong Compton cooling of the hot corona electrons and thus



to a steep hard tail. In some models the disc surface layers become strongly ionized when the accretion rate approaches the Eddington limit, which fits nicely with the detection of ionized iron  $K\alpha$  lines in a few objects. Finally the optical line width is inversely proportional to  $L/L_{Edd}$  if the broad line region is virialized and its radius is a function of luminosity alone (12), (2).

The observation of ionized lines implies that reprocessing is occurring at some level; however, the strong soft component cannot be due to disc reprocessing alone unless the primary emission is highly anisotropic or the high energy spectrum extends up to the MeV region without any cut-off. Unfortunately the BeppoSAX sensitivity at high energies is not good enough to measure the shape of the high energy spectrum especially for steep spectrum sources, and sensitive X-ray observations of NLS1s at  $E > 10$  keV are not foreseen in the near future. A reliable estimate of the amount of reprocessed radiation in NLS1s would be also extremely important to better understand the nature of the soft X-ray features detected by ASCA.

Broad band observations in the 0.1–10 keV range with better sensitivity and higher energy resolution will be/are being carried out by *Chandra* and *XMM-Newton*. The X-ray continuum shape and the intensity of any emission/absorption features will be measured with unprecedented detail. In addition, variability studies of the various spectral components will be valuable to test the leading hypothesis of an extreme accretion rate in NLS1s.

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